DUST-STORMS IN EGYPT AND THEIR RELATION TO THE WAR PERIOD, AS NOTED IN MARYUT, 1939-45

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THIS PAPER deals with the general phenomena involved in desert dust-storms as illustrated by their incidence at Burg el 'Arab in the Western Desert of Egypt during the six-year period October 1939–September 1945. Throughout this period the desert surface was subject to a sequence of mechanical disturbances incidental to military operations which culminated in the Battle of El 'Alamein (October–November 1942); thereafter a period of relative quiescence ensued.

It happened that I was able to remain in the village throughout the entire period, and as the record is probably unique and unlikely to recur, it seems worth while to make accessible some account of the occasions and general circumstances of dust-storm incidence as they came under my notice.[1] Though no meteorologist, I have some familiarity with one important factor in dust control, the vegetation covering, a circumstance which may in some degree offset inevitable deficiencies in meteorological technique. This paper, then, is substantially a record of observations on dust-storms, with some commentary, confined practically to the visible horizon of Burg.

Burg is about 30 miles west of Alexandria, and roughly half-way to El 'Alamein; it is $3\frac{1}{2}$ miles inland from the Mediterranean shore-line, thus being on the coastal zone of Egypt which derives a moderate, if irregular, winter rainfall from its proximity to the sea. This favoured zone, for want of a better term, is called "semi-desert": it extends inland some 10–15 miles.

The elements of our subject-matter are briefly the loose dust which encumbers the desert surface ("dust-reservoir"), and its relation to winds and other factors affecting its mobility.

Local topography

Before passing to the real subject-matter of this article, something may be said concerning the terrain round our station at Burg, followed by brief notes on wind and weather conditions.

Our point of observation (Burg) stands on a low mound overlooking to the south nearly level ground rising gently to the desert plateau, which reaches a height of 200 feet some 4 miles due south (*cf.* Map, p. 29, and Plate 1). To the north of Burg, $\frac{1}{2}$ mile distant, is an inner coastwise ridge followed by an outer parallel ridge 2 miles farther north. This latter overlooks the sea, distant less than 1 mile, from which it is separated by white oolitic limestone dunes. Between these two coastwise ridges is a flat valley occupied by the bed of Lake Mareotis (*i.e.* its western arm)—the level being approximately that of sea-level.

[1] An earlier paper covering the years 1940–41 appeared in January 1942. That issue, printed by Messrs. Whitehead and Morris, Alexandria, is now out of print. However all essential facts relating to this earlier period are embodied in the present paper.

This plain normally carries a close salt marsh vegetation, and, as the sequel will show, has become a contributing element in the local dust-storm production (*cf.* p. 32).

Compared with the rugged landscapes of the Eastern Desert of Egypt the Western Desert is relatively unspectacular. The wadis are not deep-cut precipitous trenches, nor is the general surface thrown into high relief. It is a gentle desert landscape which strangers at first incline to term featureless (Plate 1). The two coastal ridges reach a height of about 120 feet. The outer one alone, at a point 1½ miles north-east of Abu Sir, carries a knob, Kom el Nugus, 170 feet high.[1] This summit shows a quadrangular depression which was occupied in ancient times by a guard or outpost: traces of barrack buildings still remain. From this point the entire countryside is visible.

The accompanying sketch-map summarizes the essentials of the topography and present-day communications. The coast or "treaty" road runs in the trough between the outer ridge and the dunes. Abu Sir is the main archaeological centre with its temple and Arabs' Tower as landmarks.[2] Close by, the Burg by-road joins the coast road, after crossing the two ridges and intervening lake-bed. This by-road, as it crosses the outer ridge, follows closely the site of the old Barbarians' Wall which stretches from the lake bed to the dunes. Beyond the dunes is the sea. Presumably this wall was designed to exclude the rougher Libyan element, and may have been correlated with a garrison at Kom el Nugus, with the Arabs' Tower as a signal station.

In those Ptolemaic days Maryut was highly cultivated. Abu Sir must have been a frivolous resort for Alexandrines at pleasant seasons, with flowers or fruit, music, and boating on the lake—all with gentle pastel desert landscapes, the dazzling dunes, and deep blue, iridescent sea. Approach from Alexandria was by boat on Lake Mareotis—not possible to-day. To the south of Abu Sir jetties and harbour works still remain. From this harbour a canal had been driven to the north side of the ridge (Gebel Maryut) opposite the present Burg el 'Arab, where an ancient dock is recognizable. This was probably employed for water transport of country produce from south to north. The ground dug in making this canal was heaped on its west bank and served as a dry causeway across the lake bed. The lakeside harbour at Abu Sir was controlled by lock-gates at its western end. Beyond the lock (west) the lake bed was canalized, certainly to a point north of Gharbaniyat and probably beyond into the Hammam sector.

Wind and weather

The prevalent wind here is from the north-west sector and to its moderating influence is due the mildness of the summer temperatures compared with interior Egypt. The main departures from a state of calm are occasioned by

[1] Till lately wrongly identified with the ancient town of Plinthine; *cf.* John Ball, 'Egypt in the classical geographers,' Cairo, 1942, p. 65. Footnote by Mr. G. W. Murray. (*Note:* on the Survey of Egypt 1/100,000 sheet, Kom el Nugus is shown 3 miles to the north-east of Burg el 'Arab. In the sketch-map accompanying this paper we have shown it in the position given by the author.—Ed. *G.J.*)

[2] Plate 2, from the lake bed, looking north, shows on the skyline the Temple (lef centre), and the Arabs' Tower (right). Kom el Nugus is farther to the right, off the picture.

depressions travelling west to east, far out in the Mediterranean. These are accompanied in northern Egypt by south-east and south winds, especially in the period January to May. These passing depressions attract a flow of air from Egypt—hence these winds, which are known as Khamsin: with deep depressions, these winds blow with great violence. In sweeping the desert to the south, they have a double action. Being hot and dry, with relative humidities of 30, 20, even 10 per cent., the mantle of dust is fully dried out so that the grains lose all coherence, and in this desiccated state are raised freely into the air and carried along as dust-clouds.

A normal procedure is for a south-east breeze to spring up soon after sunrise, and as this gains a velocity exceeding 12 miles per hour, a slight opacity becomes apparent, which as the wind strengthens will, say by 9 a.m., have intensified so that visibility is cut down to such distances as 400, 200, or 50 metres. Such obscurity may continue for four or five hours. Meanwhile the wind veers to south and then, often suddenly, through south-west to west and north-west. Average wind velocities on these occasions are of the order of 20–30 miles per hour, sometimes more. As the wind reaches the north-west sector, it is no longer blowing mainly off the desert, but from the sea. This is accompanied by a marked fall in temperature. In its southerly phase the Khamsin brings temperatures approaching 40° C. (104° F.), but when it veers to the north-west there is rapid cooling and within fifteen minutes the temperature reading may drop to 27° C. (80·6° F.). These hot winds characterize the later months (April–May): earlier in the year a Khamsin may be relatively cold. But even after the wind has veered north-west the dust-storm will continue till the velocity abates. Formerly there was little loose dust to be swept up between Burg el 'Arab and the coast, but since continuous disturbances of surface through military operations came with the war the conditions have been altered, and an abundance of loose dust developed on the lake bed, as well as elsewhere.

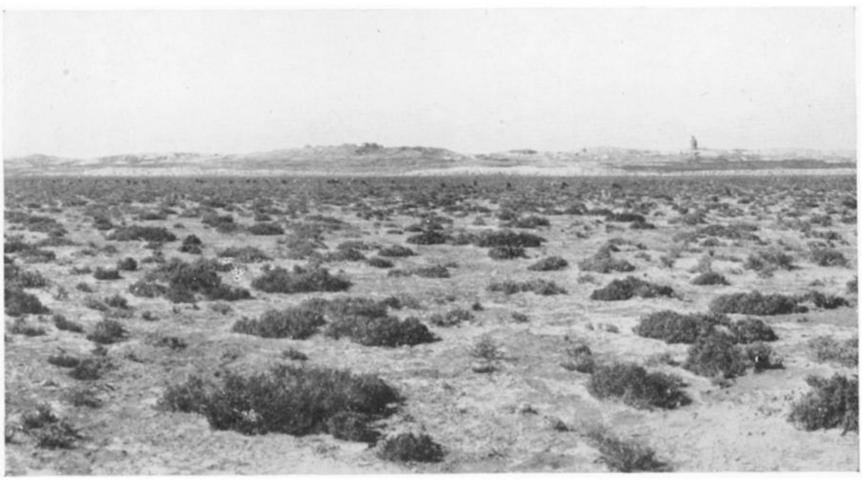
Sand and dust

It is necessary to distinguish clearly between sand and dust, sand-storms and dust-storms. While the unit particles composing sand and dust are akin and belong to the same order of matter, their behaviour under wind is entirely different. Sand lifted from the ground proceeds down-wind in a series of low hops or saltations, and as the grains under the pull of gravitation once more strike the ground they will either bounce into the air, or hitting another grain at rest, will flick it off the ground. The drift of sand is thus a cooperative or community effect. This explains why sand remains aggregated in dunes. In practice, sand advancing in a wind is restricted to a sort of creeping carpet extending upwards not more than 2 or 3 feet from ground-level—from which carpet the greater part of an erect human figure will project, except in the most violent storms.

This whole subject of sand-movement has been elucidated by Brigadier R. A. Bagnold in his recent book,[1] a contribution combining the results of field observation in the Libyan and Saharan deserts, on the one hand, and of intensive experimental studies under controlled conditions in a physical

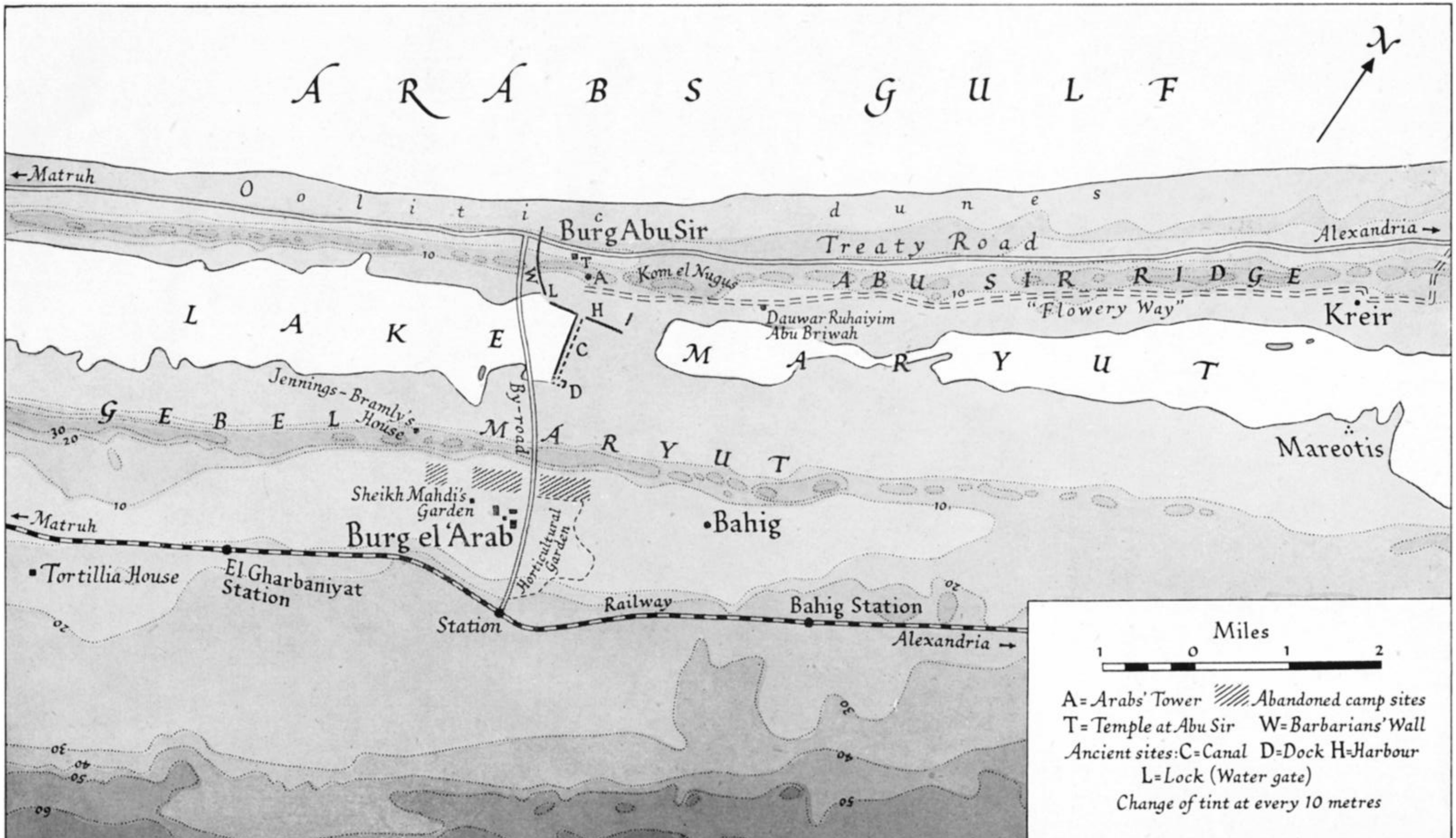
[1] R. A. Bagnold, 'The physics of blown sand and desert dunes,' Methuen, 1941.

1. Desert south of inner ridge: Burg el ʻArab left, Sheikh Mahdi's garden right



2. Bed of lake Maryut looking north, pre-war state of marsh scrub. On skyline temple at Abu Sir and Arabs' Tower

3. ʻSeil' or storm-water forming temporary lake, Burg el ʻArab, 13 Jan. 1937



ARABS GULF
N
← Matruh
Oolitic dunes
Burg Abu Sir
Alexandria →
Treaty Road
T
A
Kom el Nugus
ABU SIR RIDGE
"Flowery Way"
Kreir
W
L
H
C
D
Dauwar Ruhaiyim
Abu Briwah
LAKE MARYUT
Jennings-Bramly's House
By-road
GEBEL MARYUT
Mareotis
Sheikh Mahdi's Garden
← Matruh
Burg el 'Arab
Horticultural Garden
Bahig
Tortillia House
El Gharbaniyat Station
Station
Railway
Bahig Station
Alexandria →
Miles
1 0 1 2
A = Arabs' Tower
Abandoned camp sites
T = Temple at Abu Sir
W = Barbarians' Wall
Ancient sites: C = Canal D = Dock H = Harbour
L = Lock (Water gate)
Change of tint at every 10 metres

laboratory (including a wind-tunnel), on the other. This book marks a definite epoch in the knowledge of mobile sand.

Dust, in contradistinction to sand, consists of the smaller, lighter particles, and is incapable of these saltatory and flicking activities. Once raised from the ground dust particles, owing to their lightness, are liable to become the toy of upward or other irregular currents in the air, where they remain in suspension till such time as air-movement moderates. Dust travels in clouds, often at height, and is liable to dispersal over great distances. Certain local uni-directional winds are especially effective in this dispersal. Thus there is the Harmattan which carries dust south into Nigeria and beyond from the Western Sahara; the Haboob in the Sudan; and the Khamsin winds of Egypt and North Africa, which coming from the south-east and south, carry the Libyan dust over the Mediterranean. On particular occasions (*e.g.* March 1901) such dust has been recorded as streaking across Europe from the Sahara as far north as Sweden.[1]

Dimensions of particles.—Bagnold draws the lower size-limit of particles behaving as sand, *i.e.* characterized by bouncing and flicking, at about 0·08 millimetre. Below that comes dust which floats in the air and is subject to aerial dispersal. All my own measurements of dust falling in still air conform to Bagnold's generalization. I find dust from the Libyan Desert to range in diameter of particles from about 0·07 millimetre to mere specks of 0·002 millimetre ($=2\mu$). Dune sand ranges upward, according to Bagnold, from 0·08 millimetre to anything raisable by wind, *i.e.* up to 1 millimetre or more. In the Libyan sand used in his wind-tunnel experiments, the predominant element was about 0·3 millimetre in diameter, to which East Anglian sand dunes closely approximate. On the other hand, the sand of the Comporta dune facing the Atlantic, south of the river Sado in Portugal, is much coarser, 75 per cent. by weight of the grains falling between 0·5 and 1 millimetre.

The fate of dust is dispersal, and, under particular conditions, a considerable proportion of it must fall into the sea and ultimately find its way to the ocean floor. Sand however, whether it be blown into the sea from coastal dunes, or, water-carried, be discharged from the mouths of rivers, will in either case sink not far from the edge of the land, *i.e.* in shallow water. Unlike dust it will not be lost in ocean depths, but by the action of waves and tides in these shallow waters will be thrown back on the shore, whence suitable winds will return it to the land. Thus even in these later stages of their travel, dust and sand behave consistently: dust tends towards dispersal and ultimate fixation; sand from its "gregarious" quality, tends to remain in, or return to, the sphere of its activation.

Deflation.—This lifting and transporting power of wind by which small detached particles of the erosion-litter are removed has long been known as deflation—a general term covering all forms of wind removal. It will be evident that the mechanics of deflation differ according to the grade-size of the particles. In this article we are concerned with the finer grades (dust) which feed the dust-storms of the Libyan Desert. In this connection it was susceptible land in North America (The Great Plains) which led to the term "dust-bowl." There it was agricultural land that was being destroyed through

[1] *Cf.* J. Walther, 'Das Gesetz der Wüstenbildung,' 2nd ed., 1912, p. 65—map.

improper management; in Egypt the dust-bowl relates to desert land, agriculturally unimportant to-day. Nevertheless, two thousand years ago, the northern coastal strip was famous for its cultivations and enjoyed a high degree of fertility. But we are not concerned here with the full story of erosion and the decadence of agricultural lands involved. For this, reference should be made to two handbooks recently issued, viz. Jacks and Whyte, 'The rape of the earth' (Faber, 1939) and H. H. Bennett, 'Soil conservation' (McGraw-Hill, New York, 1939)—both are authoritative and written with full knowledge.

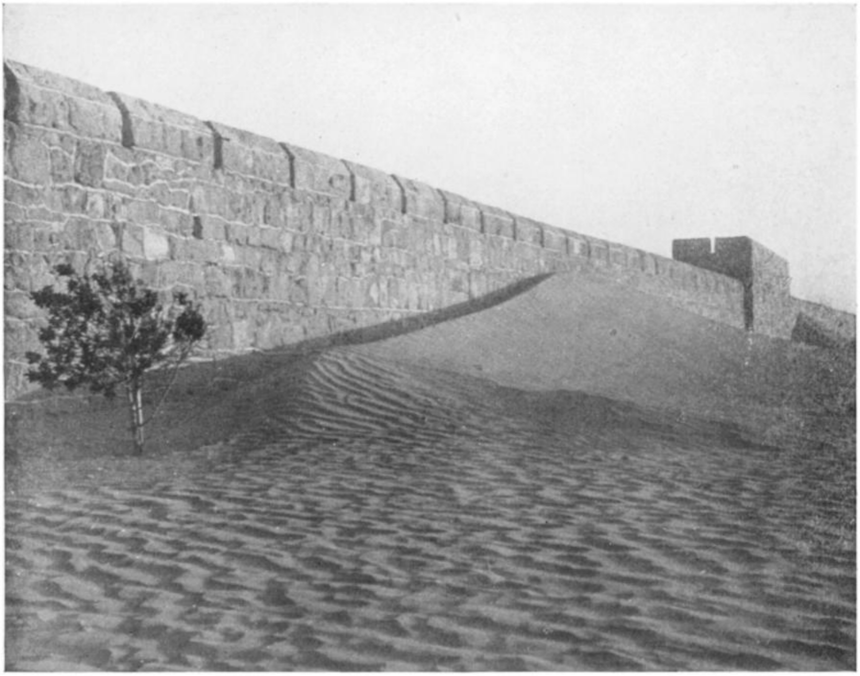
Accumulations of dust.—Should a casual visitor arriving in this district in calm weather desire to examine evidence of dust-storm incidence, he should search out depots of accumulation. These occur especially to windward of unobstructed vertical surfaces facing directions from which dust is driven. Garden walls are especially useful in this connection, being less liable to interference than houses or other occupied buildings. Such walls should be free from obstruction by other erections, trees and the like, and must face directly open desert.

Two examples from this neighbourhood are illustrated in plates 4 and 5. The latter represents the west-facing wall of Sheikh Mahdi's olive garden, 750 yards due west of the western gateway of Burg; plate 4 is from the north-west boundary wall of the garden of the Tortillia House at Gharbaniyat (3 miles south-west of Burg). These banks accumulated in a few months during the period of maximum dust-storm incidence. The Sheikh Mahdi picture was taken in April 1942; the Tortillia one in July 1943. Sheikh Mahdi's wall is 5 feet high, and there are several points where dust has piled up to the wall-top (as in the foreground where Beduins are filling sacks with dust for experimental purposes). At such points bridge-heads arise where dust drifts across and advances over the garden. The wall here runs due south to north and the bank on which the figures are standing is the west-facing bank of dust reception. The Tortillia wall (Plate 4) is 9 feet high (or more) and faces north-west. The wind had built up a spectacular "vallum" or rampart all along this side of the property. The dust intercepted to form these outworks obviously travelled low, and would be derived from low drifting dust driven before horizontal winds or from the lowest stratum of more extensive clouds.

Raising of dust.—It is no part of my intention to consider the source of dust on this desert. Obviously it is a chief product of erosion, and in amount must be greatly in excess of sand, which is definitely localized. In this district the ground consists mainly of a fine colloidal clay with rock reaching the surface at many points. Before the war, when all roads were unsurfaced (dirt tracks), if heavy rain saturated the ground all mechanized traffic was immobilized.

Bagnold, whose studies were mainly on the transport of dune sand, makes occasional reference to dust.[1] He sees in these surface-sheets a mantle relatively immobile under wind, and when grains of sand or grit are blown over it they sink into this soft matrix (or "quagmire") and go out of action. He stresses the part played by animals, human beings, and traffic as efficient raisers of dust. That is undeniable. Nevertheless, I have seen sheets of dust raised by wind, especially high-powered, gusty, turbulent winds.

[1] R. A. Bagnold, 'Physics,' etc., pp. 6, 90.



4. *Dust banked against boundary wall, Tortillia property, July 1943*

5. *Collecting dust from Sheikh Mahdi's garden wall, 4 April 1942*

6. *Dispersed camp, east of Burg el ‘Arab*

7. *Air photograph showing tanks and tank tracks*

Even on relatively calm days localized vortices or wind-eddies, called "dust-devils," may be seen here and there streaking across country. These vortices are funnel-shaped and stand on their points, sucking up the dust. Even with a small one, where the funnel may be only 10–20 feet high, it is perfectly evident that the air in contact with the ground is revolving at high velocity. I have tried to obtain readings with a portable anemometer, but the "devils" would never stay "put" long enough.[1]

But there are further alternatives. Much light litter drifts over the desert surface in a wind. This litter is largely vegetable in origin and includes tiny plant fragments, bits of fruit valves (derived especially from annual Cruciferae and Leguminosae), seeds, quantities of grass spikelets, and so forth. With them are certain elements of animal origin, feathers, the dried skins of small caterpillars, fragments of beetles, and especially much fine comminuted snail-shell (*Helix desertorum*). There is a vast population of these snails in our district; they may be seen adhering in their hundreds to bushes, especially to asphodels. In the aggregate this drift as it scours the surface must contribute substantially to the dust-lifting agencies.

In dust accumulations, whether in front of obstacles in the open, or falling from the air in a room, there is always to be found, by screening, a small percentage of this organic drift. Naturally, from dust precipitating indoors it is only the finer, more buoyant elements that will be recovered. By weight this humus fraction is trifling—0·25 to 0·5 per cent. when separated from the dust.

Military operations and the dust-reservoir

Before turning to the records and any analysis or commentary, it is convenient here to refer to the various circumstances directly and indirectly connected with military operations in the Western Desert in their relation to the dust-storm position.

Before the war, three or four dust-storms a year would be a usual number, while the first year of the war (vegetation year 1939–40) shows a slight increase to eight. By 1940–41 the number had risen to forty, and by 1941–42 to fifty-one (Table 1). Considered here are the various operations, direct and indirect, which contributed to the increase in the potential reservoir.

It will be realized that from the first Burg el 'Arab had been marked out as a key-point for the assembly of forces in anticipation of eventual hostilities, and that as early as the winter of 1939–40 our horizon was already in process of becoming a vast armed camp.[2] This depended on the fact that 'Alamein, to to the west, marked the line to be held at all costs. 'Alamein in a military sense is a "defile," roughly 40 miles wide: it is closed to the north by the sea, and to the south by the Qattara Depression—ground unsuited to military operations. Even as far back as the days of Rameses II, more than three thousand years ago,[3] there had been a battle of 'Alamein, followed by others in the reign of his

[1] Recorded in *Whitaker's Almanack*, 1938, p. 1041, are certain observations on "dust-devils" made in the Middle East (source not stated). More successful than I, records of the linear speed of rotation at the outer edge were obtained. These ranged from 10 to 40 miles per hour.

[2] *Cf.* plate 6, showing a portion of a dispersed camp, taken December 1939.

[3] J. Y. Brinton, "Some recent discoveries at el 'Alamein," *Bull. Soc. Roy. Archéol d'Alexandrie*, No. 35, 1942.

son Merenptah. 'Alamein is thus classic ground. Active disturbance became really effective following the Italian declaration in June 1940. This disturbance arose from two distinct causes, Beduin migration and military measures.

Beduin migration has been intermittent throughout, and is related to the military situation from time to time. In the earlier period, when operations became inevitable, large numbers of Beduin evacuated their usual camping grounds farther west, *i.e.* from the more exposed regions towards the Italian frontier. They straggled east into the zone, camping and grazing their herds, and cutting and pulling the scrub for fuel. Less disciplined than the normal resident population, who exercise some degree of responsible restraint in this matter, large areas became bared of scrub. It was also at this juncture that the bed of Lake Maryut was largely stripped,[1] an operation completed later by certain units of our own forces, who camped on the same ground. Then, in 1942, when our armies withdrew into the 'Alamein sector, there was a further general evacuation of nearly all Beduin of the Western Desert back to the Delta (Beheira). Following the battle of 'Alamein and the British advance into Cyrenaica and Tripoli in the late autumn of 1942, the Beduin were readmitted and straggled back once more. Even as late as the spring of 1944, due to unforeseen temporary causes, there was a further short evacuation east of Beduin from the Hammam–Burg el 'Arab sector.

In the aggregate these successive marchings and counter-marchings were responsible for much abnormal scrub-clearance, *i.e.* removal of perennial surface-cover (fuel and grazing). The most important element in this scrub is the bush *Thymelaea hirsuta*, which takes about five years to re-establish from seed. Being highly inflammable from its oily secretion this plant is much esteemed as fuel. Moreover, during the early stages of establishment the young plants are especially vulnerable to grazing animals; at one bite a goat will destroy a whole plant.[2] Military operations contribute excessive disturbance of surface with increase of reserves of loose dust. These include the breaking of surface incidental to the siting of camps, trenches, and fortifications in general (Plate 6); the laying of mine-fields, the making of roadways (chiefly non-metalled), and airfields—without runways in this district.

These are the preparatory measures. Next follows the traffic—lorries, tanks, and guns—mainly over non-metalled desert surfaces. This traffic by pulverizing the surface is unquestionably most important in the present relation. Where, for instance, lorries run between two points: at first they go direct; then as the surface becomes worn down and deteriorated to a depth of 6 or 8 inches, the drivers will choose unbroken ground alongside, till ultimately the original points are joined by an ever-widening spindle of deteriorated pulverized tracks. And as the original focal points were not static, but were moved from place to place according to changing requirements, the whole desert surface within the visible horizon became churned and overlaid by a deep mantle of dust (Plate 7). Nor did dust-disturbance cease entirely with the advance of our forces into Cyrenaica and Tripoli, following the battle of 'Alamein (late autumn, 1942).

With the new year (January 1943) demolition squads got to work with

[1] Plate 2 shows the lake bed prior to this.

[2] *Cf.* p. 33.

commendable promptitude, collecting and detonating the vast quantities of land-mines that had been strewn in protective mine-fields, together with such reserves of mines and other explosives for which there was no further requirement. These operations continued for seven or eight months (till August 1943) within our Burg perimeter. During the working hours it was usual to collect these mines into dumps. The mornings' work would as a rule be detonated about midday, and the afternoons' before sunset: six or eight explosions on each occasion.

To an onlooker each explosion took the form of a mighty uprush of smoke and dust rising to a height of perhaps 2000 feet. Normally this would show as a funnel standing on its point, whilst above, as the propulsive force exhausted itself, the mixture of dust and smoke would mushroom. Then the report of the explosion would be heard, and by counting seconds from the first visible uprush till the explosion became audible, it was possible to fix approximately the distance of the site. In calm or slight airs these mushroomed columns would drift slowly down-wind—often assuming grotesque and unexpected contours as they gradually dispersed.

Under conditions of absolute calm, towards sunset, the smoke-cloud would sometimes behave quite differently. The vertical shaft would become gathered together or contracted into a black ring, incorporating the entire visible products of the explosion. These rings floated horizontally at a height of 1500–2000 feet. They were notably stable, often persisting for twenty to thirty minutes till lost in the deepening gloom of sunset. Indeed, so permanent did they appear that it would not have been surprising had one of them survived till daybreak. Their diameter was of the order of 300 metres.

One imagines that under special calm conditions the ascending discharge acquires active spin from friction with the still air which surrounds the shaft of emission, and that this acquired spin confers on it a kind of rigidity. The rarity of this particular manifestation may be stressed: annular clouds were observed on five or six occasions in the period January–August 1943, and on warm, still evenings only. But when they did occur there would be several; a circumstance which points to the existence of particular conditions on those occasions. They suggest "smokers' rings" on a colossal scale.

These detonations, continuing for more than half a year in one locality, must have appreciably added to the reservoir of loose dust, and when the Burg perimeter had been cleared the demolition squads proceeded west continuing their work systematically. I can only state that their contribution to our dust-reservoir must have been considerable. In the circumstances a precise figure of the weight of explosives detonated is not to be expected.

It may be added that mine-fields, following the active operations of late autumn (1942), were often roughly fenced and marked with boards inscribed KEEP OFF with the added caution of a skull and cross-bones. This was to deter Beduins from wandering about in search of "souvenirs": booby-traps, and other dangerous gadgets have an irresistible attraction, and a child-like curiosity impels the Beduins to tamper with such trophies till something happens. "Unfortunate incidents" had not been lacking, nor were these occurrences in the long run without a restraining influence.

From the point of view of our subject-matter I drew the conclusion that such areas, and they were extensive, were in time respected, and avoided by men and herds. That is to say there was less habitual traffic with disturbance of surface; whilst seedlings also would have a better chance of establishment than might otherwise have been the case. Consequently, on balance, the work of the demolition squads was ultimately beneficial, in spite of their initial spectacular performances. In this relation I noted many such areas on which bushes of Thymelaea were regenerating from seed.

The records

Vegetational years.—We may now proceed to the matter of the actual records summarized in the accompanying Table 1. These records are displayed not in the conventional "calendar" or month-sequence of the year (January to December), but according to what seems the more natural or "vegetational" year, beginning with October and running through to the following September. This treatment finds local sanction, as for a number of years the Egyptian Meteorological Service has started its "Rainfall Year" on October 1. It is at this date that the dry season usually ends and rains are expected. This subdivision gives a representation of the seasons proper to the subject-matter of a paper which relates primarily to dust-storms, the most important element in whose control is the vegetation carpet which follows the rains. All references in the text to dust-storm years are in consequence cited in the form 1940–41, which means October 1940 to September 1941.

Classification of dust-storms.—The ideal basis of classification of dust-storms would be a measure of their density: the weight of dust contained in some convenient unit of space—a cubic metre, perhaps. That line of approach implies specially designed dust-traps, dust-gauges on the analogy of rain-gauges—a mechanical contrivance capable of capturing a cubic metre (or other volume) of a dust-cloud, and then determining the proportion of dust. Such an ideal was entirely beyond the available resources of a remote desert village without a mechanic, or any priorities to provide the raw materials in war-time. When I returned to Burg el 'Arab in 1939 the matter of dust-storms was not in my mind, nor any plans relating thereto. I was unprepared. Then, under war conditions, dust-storm frequency increased and records were kept. As the occasion developed it became manifest that I was confronted with an unusual opportunity for gauging the relative fixity of desert soil—hence this report embodying the main observations over the six-year period.

The only dust-collecting chamber available, without experimental equipment, was an ordinary room, which, as is usual in Egypt, freely admitted currents of air with their burden of dust. In the relative calm the dust precipitates on horizontal surfaces. It was possible to take advantage of this circumstance in two related ways:

(i) To allow dust to fall on a clean smooth surface (glass, polished wood) of known area for such a period as an hour, then to collect and weigh the dust-deposit and express it in convenient terms, such as grammes per square metre, or tons per acre. The highest figures obtained in this way were of the order of $\frac{1}{2}$ ton per acre per hour. This was during the gusty turbulent dust-storm of 14 March 1941. More frequent figures would be $\frac{1}{6}$ or $\frac{1}{8}$ ton per acre per hour.

(ii) Correlated with this was a much quicker method, viz. to count under the low power of the microscope (magnification $\times 80$, linear) the number of dust grains falling within a circle of 1 millimetre radius in a period of one minute. I found that thirty per minute corresponded approximately to $\frac{1}{8}$ ton per acre per hour—each grain of dust falling within the circle representing a contribution to the top dressing in the open of from 5 to 8 lb. per acre. The advantage of this method is that one's finger is continually on the pulse, as one might say. In violent turbulent gales, dust falls so rapidly on the slide that I found it impossible to attend to the whole area for the full minute, and had to be content to concentrate on a $\frac{1}{4}$ sector of the circle for some shorter period.

These methods are practicable only in a calm room. Their results are comparable with trying to obtain a rainfall record by collecting in jars the water that drips through a leaky roof. In other words, their value is limited. Out-of-doors they are impracticable, as a turbulent gust of wind may at any moment sweep clear the smooth surface of collection. Rough surfaces, such as fabrics with a pile, collect and hold the dust in the open, but it is difficult to correlate the results with those derived from smooth surfaces indoors.

Visibility.—The method of record adopted here is that of visibility from the station of observation. My house is provided with an open veranda extending from front to back and giving uninterrupted outlook in practically all directions. This platform being 13 feet above ground-level, and the observer's eyes about 5 feet above the platform, gives 18 feet as the height above ground-level at which visibility-determinations were made. This raising of the observer well above ground-level has in practice the effect of increasing rather than diminishing apparent visibility, thus providing an automatic check to any liability to exaggerate the density of a dust-cloud. The figures may therefore be accepted, if anything, as under- rather than over-statements.

A decision had to be reached at an early stage as to what degree of obscurity should be recognized and recorded as constituting a "dust-storm." It was decided that 700 metres should be taken as the critical distance for an "ordinary" dust-storm; that is to say that a tree or other object standing at this distance from the observer should be invisible. Higher densities are recognized as:

(*a*) "Very severe"; visibility 50 metres or less, and indicated in Table 1 by a dagger †.

(*b*) "Severe"; visibility 50–200 metres, and indicated by an asterisk *.

The distances from the observation station of the various objects used in fixing visibilities had been measured previously. All dust-storms here recorded are wind-raised and not traffic-raised. For inclusion in any one of the above categories the degree of visibility denoted must have persisted for a minimum period of one hour. A solitary gust is ignored.

The usual duration of a dust-storm is from four to five hours, though on occasion it may last all day. In the great majority of cases the wind drops towards sunset and the air clears. Frequently a storm resumes next day, or is succeeded by a following storm—these are recorded as two storms. Less frequently, a dust-storm may continue all night and well into the following day. This also is entered as two dust-storms, with an oblique stroke (/) between the dates in the record. The rule is, one day, one storm.

DUST STORM CALENDAR

Month	1939–40	1940–41	1941–42	1942–43	1943–44	1944–45	Month
Oct.	None	None	2 3 14 15 31	7 8 16* 17	2 10* 14	21	Oct.
Nov.	None	None	7 18 23	9 17 18 19 20†	3*	*1* *18*	Nov.
Dec.	None	None	2 5 6	None	None	None	Dec.
Jan.	29	12* 16 18 19 25 28†	1 7 16* 24 28 30 31*	4† 5 10 27	1* 8 18/19	*5* *30* 31	Jan.
Feb.	23	6 7 8 9 10 28	2† 3 4 11* 19 25*	22	6 8 15 17/18	None	Feb.
March	7	14† 15 21 22	17 22 25*	12 19*	*1* 3 *11* 14 *21* *24* 26* 27†/28	31	March
Apr.	5* 13 14	7 9 12 14 17* 20 27*	14 18* 24 26*	9*	*1* *2* *6* *7* *12* *16* *27* 30	*30*	Apr.
May	14 18	6 8 10 13 14 24	4* 5 6 17 20	None	15 23 26	8 *9*	May
June	None	4 18 19 20	4 25 30	15	*7* *13* 21 *27* *29* *30*	None	June
July	None	12 14 15 21	1 18 26 28 31	11*	*5* 9 *22* *26* 27	None	July
Aug.	None	7 8	18 25	6	*7* 28	*18*	Aug.
Sept.	None	2	1 4 12 13 28	None	None	None	Sept.
Total	8	40	51	20	26 + *20*	4 + *7*	
Year's rainfall	106 mm.	83 mm.	106 mm.	165 mm.	100 mm.	247 mm.	

Table 1.—The vertical columns are arranged according to the vegetational year, *e.g.* the first, 1939–40, extends from October 1939 to September 1940. The figures in these columns are the days of the months on which dust-storms were recorded:—† Very severe, visibility nil to 50 metres. * Severe, visibility up to 200 metres. Others (ordinary), visibility up to 700 metres. The figures in italic in the 1943–45 columns are the days on which sub-dust-storms were recorded, with visibility from 700 to 1500 metres.

On very rare occasions short and violent dust-storms occur at night. Actually one only is recorded in the whole period (3 November 1943). As this lasted a full hour it qualifies for inclusion. There may have been others which failed to disturb my slumbers.

It may be stated here that in my experience no dust-storm ever approached Burg el 'Arab in the form of a spectacular advancing cliff of boiling black or red dust. That type is the one usually given in book illustrations, and is I suppose the only type which lends itself to pictorial representation. Had I included here a photograph of a local dust-storm, according to its degree of severity, it would show either just a general mistiness, or nothing at all. The explanation is that Burg el 'Arab is situated within the area of dust-storm generation. As the wind rises, there will be at first a slight mistiness, and according to the velocity and other qualities of the wind, this will increase till visibility deteriorates to an extent qualifying for recognition in one of the above categories.

Under this system of recording dust-storms it is evident that dust clouds of lesser density, with more extensive visibilities, such as 1000, 1200, or 1500 metres, would be ignored. This is true in the sense that precision details concerning them were not booked, though commonly their occurrence was noted in general terms. Had these visibilities up to, say, 1500 metres been included in the regular routine, it would have increased our numbers by perhaps 15 per cent. On the other hand, care was taken to differentiate those recorded into "ordinary," "severe," and "very severe." Looking back on the whole six-year period I now recognize that this approach was ill-advised. Had I envisaged the long duration of my vigils, and the course of the military operations, which at the outset were precautionary (Italy entered the war on 10 June 1940), I might have planned the records somewhat differently. For, as we shall see later on, these minor dust-storms designated here "sub-dust-storms" became relatively much more significant, so that in the 1943–45 columns of Table 1 their dates are included, and are set in italic (*cf.* p. 44).

Some selected examples of dust-storms

14 *March* 1941.—Perhaps the most severe dust-storm in density during the period covered was that of 14 March 1941—a sort of textbook example of a very severe Khamsin. The Meteorological Service of Egypt in its monthly weather summary for March 1941 describes it in the following terms: "An unusually deep depression was centred off Sollum on the 14th March, giving rise to strong S.E. gales and Khamsin conditions; very severe storms were experienced throughout Egypt, visibility at times being restricted to only a few metres, whilst in exposed desert places it was reported as nil . . . at Helouan the velocity of the wind reached 53 miles per hour." [1]

At Burg this dust-storm, raised by a strong south-east wind, closed over the district at 9 a.m. with a visibility of a few metres only. From 11 a.m. to 2 p.m. visibility was nil, and the darkness such that lamps had to be lighted

[1] These monthly summaries I have found to be a useful check on my records; to the Director of the Meteorological Service, Mr. L. J. Sutton, I am indebted for advice and information on many occasions. For measured records of local rainfall I am under great obligations to the officers in charge of the Burg el 'Arab horticultural station.

indoors. From 2 p.m. visibility improved, extending by 4 p.m. to 400 metres. While this storm lasted for about seven hours, its maximum density at zero visibility endured for three hours (11 a.m.–2 p.m.). The dust-cloud evidently reached up some thousands of feet from the ground and drifted far out over the Mediterranean, where it discoloured the paint-work of ships of the Royal Navy several hundred miles from the coast.

A striking feature of this dust-storm was its pulsating character. While for the most part the sun was blotted out, it became just visible as a deep red disk at rough intervals of five minutes. This periodicity may have depended on one of two causes, or perhaps on a combination of both. Either the actual density of the cloud varied, or the height of the cloud was inconstant, its upper surface being ribbed and not level—such undulations corresponding to a periodicity in the gusts.

By collecting dust on this occasion, as described on p. 34, it was found that the rate of fall in a closed room reached an amount equivalent to ½ ton per acre per hour.

As the afternoon wore on the storm eased when the wind veered to west and north-west. This is the characteristic ending of most dust-storms of the Khamsin type. The following day (March 15) the wind resumed from the north sector with sufficient velocity to develop a minor dust-storm.

In the majority of cases recorded in the tables the average period during which visibility was reduced to 700 metres or less would be about four hours. Such storms generally began about 8 a.m. and would blow themselves out by the middle or late afternoon.

The storms of 26, 27, *and* 28 *March* 1944 were in part of the continuous type. On March 26 strong winds from south-east and south (Khamsin conditions) lasted till evening, when calm prevailed. Next morning, March 27, the wind freshened from the same quarter, bringing much dust, while in the afternoon it veered north-north-west without losing strength, and continued to blow all night from the same quarter (40 miles per hour), till midday on March 28.

This storm during the night of March 27–28 was remarkable for the intercalation of a short, sharp shower of rain, lasting five minutes, which drove against all windows facing west and north-west, thoroughly wetting them. This shower however was not sufficient to lay the dust-cloud which continued to drift from the same quarter till midday of March 28. The consequence was that the dust, which is colloidal and water-absorbing, congealed into a hard crust on these window-panes and had to be scraped off like paint. This is the only occasion in the whole six-year period on which this effect was observed.

3 *November* 1943.—This was a storm of exceptional type. In the early morning a violent and turbulent gale sprang up from the west-north-west sector, lasting an hour, 4.30 a.m.–5.30 a.m.; during which our flexible tamarisks were "boiling" and half prostrated. It was accompanied by a localized electric storm which circled round the village throughout the period. All the time there was continuous sheet-lightning of great brilliancy, with maximal flashes about every ten seconds. It was only during the last quarter of an hour that the storm was accompanied by thunder, which, instead of

manifesting itself in conventional thunder-claps, resembled the continuous pounding of great waves on a rocky shore. At the end of the hour the storm drifted away. There was no mistaking the violence of this display and the amount of dust that it carried, in spite of its brevity.

The "Freshet" type.—These were light showers of dust too brief for the routine records. On days of calm, or light airs from the east to south sector, puffs of wind up to 10 miles per hour lasting not more than fifteen minutes would spring up, reducing visibility to 1500–2000 metres. As the freshet died away the dust would clear. This type was frequent between July and December 1943. It may be conjectured that they derived from dry residual dust no longer detained on the ground by such remnants of desiccated herbage as still survived.

They differ from "sub-dust-storms" in that they were transient, and were raised by light puffs at 10 miles per hour. The "sub-dust-storm" was a reaction to stronger and more persistent winds at 16 miles per hour (*cf*. p. 44).

Taking all the dust-storms recorded from April 1941 to March 1944 inclusive (three years), the greater number, in the proportion of 5 to 4, came from the west and north-west sector. In the spring months however (January –May) the Khamsin type [1] is much more prevalent, *i.e.* dust blowing in from the south-east and south sector, though as a rule after a few hours they veered by south-west to north-west before calm was re-established.

Clearing of dust after a storm.—In general, following a dust-storm, while the main weight of dust is precipitated in the after-calm, there will remain in suspension sufficient finer particles to give the effect of a very thin haze. Thus, following a dusty day, a certain degree of dullness is shown by the night sky; stars, though clearly visible, are far from bright.

On 1 January 1944 we had a "severe" dust-storm which lasted from 9 till 4. By 4 p.m. the wind had veered to north-west and had fallen to slight, and later to calm. Happening to wake that night (night of January 1–2) at 3 a.m., I went to the window and looked out. To my surprise the whole firmament was alive with stars shining with a greater brilliancy than I ever remember. There had been no rain to account for this sudden transformation, and I can only suggest that possibly some electrical effect may have precipitated the residual dust. Such bright nights are familiar in Egypt, though less frequent over the desert than elsewhere. The moon, which was in the first quarter, had already set, and there was nothing to diminish the brilliancy of a spectacle new to my experience.

Following severe dust-storms, especially those from the south, one is impressed by the magnitude of the sprinkling of the landscape with fresh dust. This is especially noticeable on certain areas of which two examples may be cited. At the west end of Major Jennings-Bramly's property, on the ridge overlooking Burg from the north, is an old Roman quarry cut deeply into the ridge like a crater, and covering an area less than one acre. Scattered about on the floor of this quarry are numerous boulder-like rocks, fallen in

[1] The arabic word means "fifty": the implication being that there is liability to such storms within a period of fifty days included in the spring months, March–May. The name is traditional and popular, and should not be accepted too seriously as a scientifically defined term.

time past by earthquake action from the edge of the bowl. Visiting this quarry after a severe dust-storm, these boulders, and the ground between, were found to be smothered in a heavy top dressing of yellow dust, like new-fallen snow; and the crater being sheltered, it may be months before a heavy shower comes to wash it away.

On the lake bed between the two parallel ridges, extensive white areas develop in summer from the surface efflorescence of salt. These, after a heavy dust-storm, become shrouded by a mantle of yellow dust which may not disappear for weeks. A like effect was often noticeable on the white oolitic dunes (limestone) bordering the sea.

Commentary on the records

We turn now to the table recording the distribution of actual dust-storms, as defined by their relative visibilities (p. 36). It is evident from the nature of the measures taken in anticipation of hostilities and of the other attendant circumstances related, that the dust-potential (*i.e.* reservoir of available dust) must have been profoundly affected. All these operations, direct and indirect, must have made their contribution: the siting of camps, aerodromes, entrenching, and fortifying; the crunching and pulverizing of the surface by mechanical traction; the unregulated pulling of the natural protection of the surface; even the detonating of mine-fields and superfluous ammunition when the theatre of hostilities had moved elsewhere. It will be noticed that the number of recorded dust-storms for the first war-year, 1939–40, was eight; for the second, forty; and for the third, fifty-one. During the preceding five years the average number would have been three or four.

Assuming the provision of an adequate, *i.e.* relatively unlimited, dust-reservoir, the raising of dust-storms will depend on wind, the critical velocity for this purpose being, according to my experience, of the order of 12 miles per hour. Such winds are not very frequent. On calm days, together with such as develop an air movement that may be denoted as "slight", winds of 7 or 8 miles per hour form the majority. This holds good even in the windier months (January–May), while from June to December, twenty, twenty-five, or even thirty calm days per month are not unusual. Even in the year of maximal incidence (1941–42), with fifty-one recorded dust-storms, the average is just about one dust-storm a week.[1]

Humidity and plant cover as inhibiting factors.—As a rule when high wind is accompanied by heavy rain, there is no dust-storm. The dust is laid. Recovery from rain however is often rapid—especially when followed by hot drying winds from the south. Thus, to take an extreme example, on 28 December 1942, a very heavy shower on the desert near Burg brought a flood of run-off (*Seil*) which inundated the ground all around the village to a depth, in places, of several feet.[2] By midday, December 29, this had mainly disappeared, chiefly by percolation, leaving the surface sloppy. In spite of some further rain in

[1] Even in this year of maximal activity of dust-storms, under 5 per cent. of the entire span of time was so occupied. Averaged out, it means a trifle more than an hour a day all the year round. What is so impressive a quality of desert life, the calm and silence which generally prevail at the rising and setting of the sun, were rarely infringed.

[2] Plate 3 shows such a flood close up to the western entrance of Burg (13 January, 1937).

the first days of January 1943, a violent Khamsin gale from the south on January 4 was able to raise a "very severe" dust-storm.

A high relative air humidity also inhibits dust mobility to some extent owing to the colloidal character of the dust. However a hot wind from the south, with relative humidity 20 per cent., quickly dries it up again. On the whole, to this cause can be attributed little more than a slight delaying action. Even a north-west gale off the sea, with relative humidity 70–80 per cent., can raise dust surprisingly quickly.

Apart from sluggish airs and humid conditions, the degree of covering of the surface by vegetation must not be lost sight of as a stabilizer of dust. This will appear in due course (pp. 48–9). From this angle a plant is a trap to catch dust.

The dust-reservoir and its fate.—It is not possible, except at undue length, to analyse in detail the circumstances of the dust-storms of the years 1940–41 and 1941–42. We must be content with the statements that these were both years of low rainfall (83 and 106 millimetres respectively) and of sparse vegetation, and that the frequency and velocity of wind for these years was in no wise excessive as compared with the preceding years; if anything they were less windy than 1939–40. Consequently, the dust-storm frequency would appear *a priori* to derive from the abnormal and artificially produced surplus of dust due to causes set forth above.

By 1943 the zone of hostilities moved away west, and a point of some interest arose. As ground disturbance gradually subsided, would the inflated dust-reservoir be consumed without replacement, and dust-storm frequency revert to normal? Or, on the other hand, was it possible that the artificially created erosive process, once started, would become chronic? In America and elsewhere it is recognized that wrong management of land has often been the operative cause in initiating certain types of erosion ("dust-bowl" phenomena) which, once started, have been found to require drastic methods to eradicate. As one may say, erosion sometimes breeds erosion.

How would our desert react now that it was about to be left relatively to itself once more? Would it gradually recover, following the exhaustion of the artificially created dust surplus, or would such dust production persist as a sort of acquired habit?

Finally, would the scrub that had been destroyed, depriving the surface of its natural cover against wind, regenerate from the reserve of seeds nearly always dormant in desert soils?

Three years in detail: 1942–43, 43–44, and 44–45. From the columns for these years, it is evident that dust-storms have become less frequent, and have fallen from fifty-one in 1941–42, to twenty in 1942–43, twenty-six in 1943–44, and four in 1944–45. As these years appear to mark a transitional phase which may be critically important, they merit fuller consideration.

So far as my experience of the Maryut flora goes it would appear that two conditions must be fulfilled for the production of a good display—which is largely based on annual plants: there must be a total rainfall extending over the period October–April considerably in excess of the mean, which is about 115 millimetres, and the showers which bring the rain should appear at frequent intervals—the ideal being a good shower every ten days, with maximal incidence in January. It was in such conditions, obtaining in the winter and spring of 1937–38, that a bumper display hardly known in living memory was produced. The nearest approach was in 1929–30; also a season of high rainfall. The four following seasons (1938–39 to 1941–42) had an average rainfall of 103·5 millimetres (the extremes being 83 and 119), with production of sparse flora and very little barley.

Table 2. Monthly Rainfall in Millimetres

	Oct.	*Nov.*	*Dec.*	*Jan.*	*Feb.*	*March*	*Apr.*	*May*	*June–Sept.*	*Total*
1942–43	20	14	25	43	28	19	11	5	none	165
1943–44	17	6	22	34	19	2	none	none	none	100
1944–45	Oct. to Jan. 165				56	17	4	5	none	247

Details of rainfall for the vegetational years 1942–43, 43–44, and 44–45 (Burg el 'Arab) are contrasted in the text, below

Details of 1942–43.—In 1942–43 there was marked increase in rainfall on the preceding years, as set out in Table 1. The distribution in time was also excellent (Table 2): fairly even monthly amounts in the first three months (October–December); heavy rains in January, with gradual decline till the summer's drought.

The progress of plant establishment was as follows. By early January a generous germination of seed was apparent on all classes of terrain—the higher plateaux, slopes, and lower ground. With a copious rainfall continuing, these seedlings, which started out as mere points, gradually expanded so that by the end of January they must have covered almost half the desert surface. February and March continued the good work, so that at its maximal spread the wild flora occupied on the average quite three-quarters of all the ground.

In this display three Cruciferous species (all annuals) played the most conspicuous part, *Carrichtera annua*, a white-flowered congener of the mustard; *Enarthrocarpus lyratus* (cabbage tribe), yellow petals with purple blotches; and *Matthiola humilis*, the mauve-coloured sea stock—the relative frequency of these three species was in the order of their enumeration. In habit they were all of the more or less prostrate type and they continued to expand right through the season up to May and even June. Quantities of other plants cooperated with these, but as this is not primarily a botanical paper, two only may be mentioned by name: *Centaurea glomerata*, a prostrate, yellow-flowered composite which crawls on the ground, continually forking; its mats often reached a yard in diameter that year. The other, a trailing annual of the Leguminosae, *Trigonella stellata* (one of the fenugreeks), with bright yellow heads of sweet-scented flowers.

During February there were two occasions when the wind blew hard. The first, on February 12–13, of Khamsin type from the south, failed to produce a dust-storm. Later, on the 22nd there was a violent squally gale from the north-west (50 miles per hour in the gusts): this raised a dust-storm. In March there were high winds on eight occasions. On the 12th and 19th dust-storms were recorded, on the 21st rain fell in quantity, keeping the dust on the ground; while on five other days, when strong winds blew, any dust raised was negligible. In April there were six days of high wind; that on the 9th produced a severe dust-storm. Another on the 12th was accompanied by rain, while on the four remaining occasions dust again was negligible. May was a month of calm weather mainly—on four days there were fresh winds blowing (15 miles per hour), but no dust-storms were raised.

During the four remaining months (June, July, August, September) the weather was mainly calm, apart from a total of thirteen days on which winds of 25 miles per hour developed. Of these winds those on June 15, July 11, and August 6 alone were accompanied by dust-storms. This leaves ten windy days during this period when no dust was raised considerable enough for record.

Summarizing these eight months, February–September inclusive, there were thirty-two days of high wind (omitting March 21 and April 12, when the wind was blanketed by rain) of which seven raised dust-storms of various categories, while twenty-five failed to raise appreciable dust.

This was an experience without precedent in 1940–41 and 1941–42. The decline in dust-storm incidence must depend on some factor absent in the two seasons cited. It can be related only to the well-developed vegetation mantle of 1942–43. Exploring the ground repeatedly it was perfectly obvious that the plants were holding the dust. That they continued thus to function right on into the autumn depended on the fact that even when their shoots and leaves dried up under the summer heat, there was no disintegration till much later. Indeed it is probable that the new-brought dust, held by these plants, operated as a fertilizer and promoted maximal growth, *i.e.* so long as moisture was available.

It may be emphasized that this was the first year within the war period in which the natural vegetation was sufficiently developed to operate as a controlling factor in relation to the dust nuisance.

Details of 1943–44.—Climatically this year contrasted with 1942–43 in that the rainfall which started, not without promise, with 17 millimetres in October, and up to the end of January was adequate for the establishment of seedlings, failed thereafter. After February 8 (apart from a brief shower in the night of March 27–28) no rain fell in Burg (*cf.* Table 2). Consequently there was no effective expansion of seedlings as had been the case the previous year. Right up to midsummer the unit plants rarely reached a diameter exceeding a few inches, instead of feet as in 1943. If the vegetation covered 75 per cent. of the ground in 1942–43, in 1943–44 it did not exceed 10 per cent.

This sparsity of the carpet in the latter year would appear therefore to stand in direct relation to the recorded increase in dust-storm incidence.

Details of 1944–45.—This was a year of unusually heavy rainfall, with total of 247 millimetres. The major part fell in the four months October–January (165 millimetres),[1] and was followed by 56 millimetres in February. Vegetationally the spread of plant cover was complete, though the actual floral display at any one moment was less impressive than that of 1937–38, when spells of cooler weather retarded premature flowering until March.[2]

That dust-storms should have diminished markedly in such a season was inevitable in any case. The fact that even when the cover died off (June–

[1] From accidental circumstances the total only is available for the four months.

[2] *Cf.* "Flowers of Mareotis," *Trans. Norf. and Norw. Nat. Soc.* 14 (1938) 407.

September) only one dust-storm was recorded (and that a sub-dust-storm *cf.* Table 1) indicates that the dust-reservoir was by this time largely depleted.

Sub-dust-storms.—This however is not a complete statement of the position. Already (p. 37) passing reference has been made to what have been classed provisionally as "sub-dust-storms," *i.e.* such as failed to reduce visibility to 700 metres. Had these been included, dust-storm incidence would have been increased numerically by 10–15 per cent.

Now, during the period February–September 1944, there were eighteen dust-storms with visibility 700 metres or less,[1] and twenty sub-dust-storms with visibility of 1000–1500 metres, as Table 1 shows. These latter were raised by winds of intermediate velocities averaging about 20 miles per hour, which according to the experience of previous years (excluding the spring of 1943 when there was good vegetation cover) should have raised dust-storms having visibility restricted to the 700-metre limit.

My suspicion that we were entering a new phase was aroused, and the state of the surface was examined on many occasions and along various radii. It appeared that the surface was slowly hardening—in other words that what has been termed the "reservoir of dust" was approaching exhaustion. Lack of dust was becoming the limiting factor. This matter is pursued in the next two sections.

Wind velocities and dust-storm types.—It is convenient here to consider the relation of wind to dust-storms (including sub-dust-storms) at different periods with a view to gleaning evidence on the exhaustion of the mobile "dust-reservoir," whether by attrition, *i.e.* deflation, or by consolidation with the desert surface. It is evident that following the march of our armies west after the battle of 'Alamein in December 1942 a main factor in abnormal dust production would cease to operate, although this may have been somewhat retarded by the subsequent activities of the demolition squads from January to August 1943 (*cf.* pp. 32–3) in removing the local mine-fields. For the purpose of contrasting the dust-reaction to wind in the several years reviewed, the period February–September is taken throughout, whereby the blanketing effect of rainfall is largely eliminated. For comparison, dust-storms are grouped in three classes—"ordinary," "severe and very severe," and "sub-dust-storms" (Table 3).

Table 3. Wind Velocity in Relation to Types of Dust-Storm

Feb.–Sept.	*Ordinary D.S.*	*Mean wind vel.*	*Severe and v. severe D.S.*	*Mean wind vel.*	*Sub-dust-storms*	*Mean wind vel.*
1941 ..	31	16 m.p.h.	3	29 m.p.h.	—	—
1942 ..	26	18	7	26	—	—
1943 ..	4	28	3	37	—	—
1944 ..	16	27	2	40	20	16·5
1945 ..	2	35	0	—	3	25

The outstanding feature of this table is the contrast presented between the mean wind velocities required to produce the same results in the earlier and

[1] This compares with seven for the same period in 1943.

later periods. In the years 1943 and 1944 the wind velocity necessary to raise "ordinary" dust-storms had increased by about 10 miles per hour as compared with 1941 and 1942. In other words, the mean velocities previously required for the more severe types had now become competent to generate only "ordinary" dust-storms of 700-metre visibility. In 1945 this mean velocity requirement had risen to 35 miles per hour.

Sub-dust-storms are cited for 1944 and 1945. In the earlier period such storms were associated with a low relative wind velocity such as 7 miles per hour, while in 1944 they were accompanied by winds averaging 16·5 miles per hour, which is substantially the same as was required in 1941 and 1942 to produce an "ordinary" dust-storm of 700-metre visibility. Further, these twenty sub-dust-storms came in two groups: eleven in March–April, and nine in June–August. The mean wind velocity of the earlier group was 13·9 miles per hour, and of the later 19·7 miles per hour. In 1945 the mean wind velocity for sub-dust-storms had risen to 25 miles per hour.

Broadly speaking, these figures indicate that with passage of time much higher wind velocities were required to produce the results for which lesser winds had sufficed in the earlier phase. In other words the mobile dust-reservoir was now becoming less effective as a source, either through depletion, or perhaps by consolidation.

The immediate effect of the departure of our Forces in December 1942 was masked by the very adequate plant cover which spread itself everywhere as from January 1943. Table 3 shows seven dust-storms (*i.e.* four "ordinary" and three "severe") for the period February–September 1943, as compared with thirty-three in 1942 (twenty-six "ordinary" and seven "severe"), *i.e.* a shrinkage to less than one quarter. Evidently depletion of dust through deflation must have been greatly retarded, while a further effect of the plant cover may have been to accelerate consolidation of dust by raising moisture from lower levels together with any direct shelter from evaporation such cover might afford. This latter point will require a special investigation in a suitable season for its elucidation. The data displayed in Table 3 are no more than a record of what actually happened under the free play of natural forces combined with successive phases of military disturbance: it was no planned scientific experiment of the nature suggested above.

Otherwise, these three seasons (February–September 1943, 44, and 45) are in general agreement as to the need of increased wind velocities to produce the effects of the earlier phase (1941 and 1942). This agreement however depended on different causes, in 1943 on plant cover, in 1944 on a more intractable soil which it may be conjectured was due to a process of soil consolidation. The section which follows appears to be consistent with this idea of auto-recovery of disturbed desert surfaces.

The abandoned camping-grounds.—An accidental circumstance extending over the period midsummer 1943 to April 1944 provides valuable testimony in this matter. This relates to a strip of desert ground about $1\frac{1}{2}$ miles long (east to west) and $\frac{1}{4}$ mile deep (north to south). It lay just north of Burg el 'Arab and extended from the north-east corner of the Horticultural Garden to a point on the level just south of Major Jennings-Bramly's house. Unlike so much of the ground about Burg this strip had not been camped on till midsummer 1943, though its surface had been previously highly mobilized everywhere by lorry traffic. Three small separate camps were established on it at the date given; an Indian battalion occupied the east half of the strip; the central section was allotted to an R.A.M.C. unit; while at the west end was another small camp where Red Cross ambulances were parked and serviced. Now it happened that all three camps were evacuated at the same time, viz. the week-end 7–9 April 1944, and all camp furnishings, tents, etc., removed. Following April 9, there was no interference or traffic of any kind on the sites of these camps; in fact the wire entanglement fences had been left in situ, so that interference was impracticable.

Keeping these lately evacuated sites under observation I noticed that much dust had drifted on to what had been sheltered alley-ways between tents and other camp erections (this is usual with camps—dust comes to rest and accumulates between obstacles where it finds shelter); that whenever the wind blew at more than 10–15 miles per hour the sites of the three abandoned camps were "smoking" with dust—three little, isolated dust-storms. Wind was now finding access to those previously sheltered spots, and the accumulations of dust were being gradually shifted—a state of affairs which continued throughout the rest of April, May, and June, whenever such wind velocities prevailed; and that on the other hand the adjacent ground which had not been camped on did not liberate dust except under very much higher wind velocity, 20–30 miles per hour.

It would appear therefore that chance circumstances had provided a sort of "lecture table experiment" demonstrating: the high mobility of the ground of just evacuated camp sites; and the capacity of adjacent terrain, rendered mobile by traffic at a much earlier period, to recover up to the point at any rate of not feeding the gentler winds but requiring higher velocities (20–30 miles per hour) to ruffle its tranquillity. Had the whole thing been designed and carried out with the help of a labour squad the details could not have been improved on. The point of this observation of abandoned camp sites is the simple and convincing way in which it differentiates between old ground, well advanced in restabilization, and adjacent ground whose mobility has been rejuvenated through military disturbance. In this case it required about twelve weeks for the camp sites to recover and enter the more resistant phase. The incident occurred in a very dry year (1944) so that no complication arises from the presence of vegetation cover.

Some inferences.—The evidence indicates that desert ground of this type if left to itself after surface disturbance does tend to stabilize itself, at any rate within certain limits of wind velocity. But that such recovery can be absolute in a countryside like Maryut, infested as it is by Beduins and their live-stock, is improbable. From time immemorial Maryut has been liable to occasional dust-storms (three or four a year since 1930); and any one who has had experience of the penetrating and searching power of hurricane weather of 50 miles per hour in this district would probably agree. Nothing less than a continuous vegetation mantle with ample provision of shelter-belts of scrub and tamarisk could cope with such conditions. However the present article claims to be no more than an objective report on a definite experience; desert planning is beyond its scope.

Change of phase.—And now to return to the dust-storm tables. At the outset three degrees of visibility had been devised as suitable for record, the greatest visibility degree for formal recognition being 700 metres. At that time, when surfaces were subject to traffic and other disturbance (p. 31), there was available a growing dust-reservoir from which practically all winds over 12–15 miles per hour (unless blanketed by rain) could raise dust-storms within the defined limits. At a later stage an increasing number of sub-dust-storms, giving visibilities of 1000–1500 metres, became noticeable; these attained maximal incidence in the period March–June 1944.

The presumption is that the phase of greater activity is drawing to a close. Had I permitted myself at the outset to let my mind dwell on possible sequels, one would have been the inevitable decline in the incidence of dust-storms. The catastrophic is transient. Consequently in those earlier days, though distant haze on the desert was frequently recorded, these entries were not generally accompanied by wind velocities, instrumentally taken. In the circumstances the original plan of record has been retained throughout, except that when these sub-dust-storms could no longer be ignored, and indeed appeared to be significant, I have since February 1944 included them in the tables. The dates of these sub-dust-storms are set in italic in Table 1, thus—*6*.

In the spring of 1941 (March–June) there were twenty-one dust-storms; in 1942 (March–June) fifteen. In the same period of 1944 the number had declined to ten, with the addition of sixteen sub-dust-storms (visibility 1000–1500 metres).

It may be added respecting 1944, that the average wind velocity raising those ten dust-storms was 30 miles per hour, while the corresponding figure for the sixteen sub-dust-storms over the same period was 16½ miles per hour. In the earlier days of my records, other things being equal, a wind of 16½ miles per hour would have raised dust-storms with visibility reduced to 700 metres or less. To-day such winds produce no more than sub-dust-storms. Evidently the texture of the desert surface is growing more resistant.

The spring of 1943 (with four dust-storms in the same period, March–June) was not comparable with either of the two preceding springs, nor with that of 1944, for the reason that it alone of the three had an ample vegetation carpet.

The lake bed.—In concluding this section some reference must be made to the dust contributions deriving from the lake bed (salt marsh) area lying between the two parallel rock-ridges to the immediate north of Burg. As stated on p. 32 its vegetation was severely destroyed in the earlier years of the war. Following this a forward hospital was established there in 1942 with constant traffic of ambulances, as well as of aircraft on a temporary landing-ground. The surface, already denuded, became thoroughly churned up and much loose dust accumulated. Even in September 1944, though there had been little traffic on the lake bed for eighteen months, it was still a source of dust-clouds under wind from the west and north-west. Its "reservoir" was not then exhausted. The greater the westerly component, whereby the wind blows directly or obliquely along this valley, the greater the movement of dust.

With winds due north and north-east, when the wind blows transversely across the valley, owing to the diminished "fetch" and the appreciable shelter given by the northerly ridge, less dust is set in motion. As the salt marsh vegetation (largely perennial) re-establishes itself the surface should stabilize once more. Plate 2 shows the pre-war phase; for its present appearance it is only necessary to wipe out most of the foreground.

Dust-storms and rainfall

Table 1, while presenting in detail the dust-storm incidence for the six war years (1939–40 to 1944–45), includes a statement of the relevant rainfall totals. Of these totals, two stand out from the rest, 1942–43 with 165 millimetres and 1944–45 with 247 millimetres. The other four, all deficient in amount, average 99 millimetres per annum.

Such fluctuations are characteristic of the district. To go no further back than my own contacts: 1929–30 was a season of abundant rainfall (well over 220 millimetres) with fine display of plant cover and barley crops. This was followed by a series of seven more or less lean years, over which the rainfall averaged about 120 millimetres per annum. Then came 1937–38 (257 millimetres), with bumper crops and a spread of wild flora such as the oldest inhabitants had not seen for forty-one years. To me it seemed like a miracle. The next season (1938–39) showed a deficient rainfall (119 millimetres).

This variable type of rainfall is evidently of very long standing, and accounts for the many hundreds of collecting tanks (cisterns) and other contrivances along this coast-line which have survived from ancient times. Those old peoples were well aware of the potential fertility of desert soils when mixed with water, and possessed the skill and tenacity to make the necessary provision. With the Arab conquest (seventh century A.D.) came a set-back, and it is only in recent years that (apart from barley) the older cultivations are being revived.

But to return to Table 1. The years 1940–41 and 1941–42 were the peak years for dust-storms (forty and fifty-one respectively); they were also the two years of maximal disturbance of desert surface, as well as being years of drought.

When the armies marched west (winter, 1942–43), apart from clearing of mine-fields and the like, there remained little local ground activity to swell the dust reservoir. Dust-storms fell to twenty, this sudden contraction in number being largely dependent on the plant cover promoted by a rainfall of 165 millimetres.

The last year of the series (1944–45) shows a most marked diminution of both standard and sub-dust-storms—the numbers almost approximating to pre-war. The highly developed plant cover of this year, corresponding to a very abundant rainfall of 247 millimetres, would in itself account for this until it died off at the end of the spring. None the less the later months of the season (June–September) showed no increase in dust-storm incidence, as for that period the record shows only a single sub-dust-storm (Table 1).

Concurrently, the perennial desert scrub which had been so heavily sabotaged in the earlier war years showed continued rejuvenation, in which relation the marked increase of vigorous young plants of *Thymelaea* (a keyplant) may be stressed. The lake bed which suffered severely is also recovering and should resume its pre-war spread within a year or two.

On all counts the dust episode that accompanied the various operations of war has now subsided: nor is there any evidence of the severe erosion phase to which the desert surface was subjected in the earlier years having any permanent deleterious effect.

The following year (1943–44) was one of drought with much greater exposure of surface due to paucity of cover. The number of dust-storms of types as previously recorded rose to twenty-six, and in addition to these there were twenty sub-dust-storms (visibility 700–1500 metres) raised by wind velocities which on the precedent of 1940–41 and 1941–42 should have raised dust clouds of full standard type. Frequent inspection of familiar ground however convinced me that the volume of loose dust on the surface was becoming seriously depleted, and that exhaustion of the dust reservoir had become the limiting factor.

In the branch of meteorology which relates to dust-storms three principal variables are involved: wind velocity, plant cover, and available dust reservoir. Actual rainfall in its direct action as a stabilizer of the surface is relatively transient in its action. In a wind, and especially in a hot wind, surface dust dries rapidly—often in a few hours. The true significance of rain in this matter is its indirect action as a promoter of plant cover. In this relation there is analogy between plant cover on a desert and wind-raised dust, on the one hand, and the protection against water-erosion afforded by forest canopy on hilly ground, on the other.

In the foregoing account little reference has been made to the biological aspect of dust, apart from the restraining action of plant cover. From that angle a variety of matters arise, including: the composition of dust and its fertility value in relation to vegetation; its effects on the animals of the desert; the opportunity afforded by the natural regeneration of areas denuded of scrub for the entry of other perennial plants which might become permanent members of the scrub community; and measures for the control of dust drift at ground level, especially by appropriate planting. These and other topics proper to the biological field may conveniently be postponed to a later occasion.